Human Systems Integration (HIS)

-Associated Development Activities in Japan -

12 June 2008

Dr. Hitoshi Narita

Submitted to Asian Office of Aerospace Research and Development
and
Office of Naval Research-Global, Asia

Report Documentation Page						*Form Approved OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.						
1. REPORT DATE **30 JUL 2008**		2. REPORT TYPE **FInal**				3. DATES COVERED **27-12-2007 to 16-06-2008**
4. TITLE AND SUBTITLE **Human Systems Integration (HIS) Associated Development Activities in Japan**						5a. CONTRACT NUMBER **FA48690714094**
						5b. GRANT NUMBER
						5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Narita Hitoshi**						5d. PROJECT NUMBER
						5e. TASK NUMBER
						5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Hiroshi Narita,4-23-5 Kichijojiminamicho,Musashino City Tokyo 180-0003,JP,180-0003**						8. PERFORMING ORGANIZATION REPORT NUMBER **N/A**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **AOARD, UNIT 45002, APO, AP, 96337-5002**						10. SPONSOR/MONITOR’S ACRONYM(S) **AOARD**
						11. SPONSOR/MONITOR’S REPORT NUMBER(S) **AOARD-074094**
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT **This report covers the following topics: (1) Development of a user-friendly Japanese product -- ?Washlet;? (2) Challenges of Suwa industrial accumulation: co-evolution of technologies in industries and researches in universities; (3) High-performance CFD-based global optimization for high-speed multi-hull ship design; (4) Decision making training through gaming simulation and agent-based modeling; (5) Application of genetic algorithms to plant design problems; and (6) Extracting tacit knowledge of plant operations through machine learning and data mining technologies**						
15. SUBJECT TERMS **Energy Conversion, Human Effectiveness, Thermal Protection and Control, RF Devices**						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**20**		

Table of Contents

Key words: Human Systems Integration (HIS), Washlet, Suwa Industrial Accumulation, Ship Design, CFD-Based Global Optimization, Genetic Algorithms, Decision Making Training, Gaming Simulation, Agent-Based Modeling, Machine Learning, Data Mining

Executive Summary

In the USA, the Human Systems Integration Initiative (HSI) is vigorously promoted by the Department of Defense. The objectives are to optimize the total system performance, minimize total ownership costs, and ensure that the systems are built to accommodate the characteristics of the user population that will operate, maintain, and support them. The purpose of this paper is to inform the US community of some features of HIS development in Japan which may be valuable to US efforts in design, production, and operation.

As a small but noteworthy HSI example, the Japanese company TOTO developed a hit product, the so-called ‘Washlet,’ to provide improved comfort for the toilet users. Through continued efforts with dedication and perseverance of the team members over a span of a few decades, its market share at homes in Japan has now reached a level higher than 60 percent. (Chapter 1)

Although Japanese large manufacturing companies such as Toyota are often talked about, one of the unique aspects of Japan is that some small regional industrial accumulations are developing innovative technologies and products, as well as supporting the large companies with their unique skills and technologies. As an example, opportunities and challenges of the Suwa Industrial Accumulation Research Center are introduced. (Chapter 2)

To design a logistical ship, not only its speed but also its motion characteristics have to be studied, so that the work efficiencies of military personnel onboard and flight deck operation should be taken into consideration. A genetic algorithm (GA) was successfully applied to develop a large high-speed catamaran for logistical support, under the collaborative research by the University of Iowa, Osaka Prefectural University, and INSEAN, Italy, under the sponsorship of ONR. This joint research has successfully demonstrated a method of ship design optimization to secure high operational capability by introducing HSI concept in the early stages. (Chapter 3)

Prof. Takao Terano, Tokyo Institute of Technology, successfully developed a business game program that integrates case studies and gaming simulation. This is a new approach of training people in decision making, and would be applicable to military systems for decision making and/or training with certain modifications. (Chapter 4)

To design chemical plants a set of numerical differential equations are required for Monte Carlo simulations, which is a time consuming process. A new approach was developed to generate multiple design plans within the first requirement specifications referring to the past plant designs. Then the hybrid technique with GA and Tabu-search in Operations Research literature is adopted to estimate the range of the feasible region among the plans. (Chapter 5)

In order to extract the tacit knowledge of plant operations through machine learning and data mining, a new method applicable to varieties of plant operations is proposed. The method will generate workflow processes and also enable human expert operators to support to discover implicit plant operation knowledge. Such knowledge is useful to transfer experts’ special skills to naive operators. (Chapter 6)

1. A Success Story of Development of a User- friendly Japanese Product -'Washlet,' which changed the toilet culture and realized HSI-

The `Washlet` is the brand name of a hit toilet product which was developed by a Japanese company called TOTO located in Kita-Kyushu, Japan to minimize the unpleasant factors of the traditional toilets and to provide extensive new features of greatly improved comfort for the toilet users. Its innovative features include automatic washing of the rear end and bidet functions, which are performed with directionally controlled warm water spray and dry warm air, eliminating use of the paper. The seat is properly warmed-up and the toilet room is deodorized by catalyst. For the successful development of this product extensive investigations of location of the objects to be washed had to be made to satisfy all the potential users. This product has been continuously improved by adopting micro-computers and other new technologies since 1980, and the market coverage of their advanced products used at homes in Japan as of March 2007 reached to 65.3% according to the Japanese Government statistics. Today, the `Washlet` is sold also in the US market.

The TOTO was established in 1917 as a ceramic technology based company, and has grown with their breakthrough technologies in ceramic glazing among others. Their main product lines are composed of the series of system kitchens, system bathrooms and toilet systems including `Washlet` series, all of which are associated with the market associated with activities using water. They also have the super- hydrophilic photo-catalyst technologies for licensing to support its broad applications. Their annual income during FY 2007 was US$ 4,338mill.

There are certain common aspects in the required features between this `Washlet` development and the variety of HSI projects in that both require the user- system friendliness as well as the high system performance at a reasonable cost, although the project scale might be different. The story of successful `Washlet` development by TOTO team members by overcoming many practical obstacles with perseverance would serve as a success model of collaboration among the team members of future HIS projects.

Fig. 1. "Washlet" added part

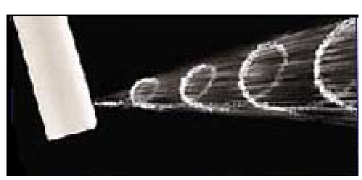


Fig. 2. Wonder spin water jet

Fig. 3. Automatic opening/closing

2. Challenges of Suwa Industrial Accumulation: Co-Evolution of Technologies in Industries and Researches in Universities

Japanese manufacturing industries are well known worldwide for the activities of large companies such as Toyota, Nippon Steel, Sony, Panasonic, and so on.
However, it is not well known the fact that there are so many small manufacturing firms to support their activities behind the big names. Such small manufacturing firms have the unique top-level skills in the world and short delivery for various manufacturing requirements. Such regional industrial accumulations have long histories and unique characteristics in Japanese industry.

One of the most active industrial accumulations in Japan is found in Suwa/Okaya/Chino area in Nagano, which is located about 200 miles west of Tokyo. They produce, for example, special parts of Formula-I racing cars, ASIMO robots of Honda and so on. It takes only one or two days from order to delivery.

However, facing the movement of mass production facilities from Japan to China and other Asian countries, they are seeking for new industry formation to exploit the strength of the industrial accumulation. Furthermore, most of the regional areas in Japan also face the problems of aging of skilled workers, changes in consumers' tastes, and changes of life styles. To cope with these issues, they have organized the Suwa Industrial Accumulation Research Center (SIARC) under the collaborations with industries in Suwa area and researchers in various disciplines from universities, such as Tokyo University and Kyoto University. The main objective of SIARC is to develop a Network of Excellence (NOE) for future Japanese industries.

Traditionally, industrial accumulation in Suwa area has played a role to support development and manufacturing of precision parts used in watches and cameras manufactured by large companies in that area. Therefore, they have had very small direct channels to provide their products to consumers, and have not been recognized the existence of such factories. Because of the Asian shifts of mass productions, the rapid development of Information and communication technologies, the decrease of population in younger ages, recently, small factories in Suwa area have reduced their production powers in manufacturing development.

To cope with the recent situations, they have established SIARC. The activities are another example emerged in network societies [1] to harness complexity [2]. The objectives are summarized as follows:

1) Develop Experimental Products for Research Objectives
   Recently, universities with engineering departments in Japan are gradually decreasing their abilities to make experimental products, because of the decreases of engineers inside of universities, who are able to make experimental mechanical systems. Manufacturing people in Suwa area have found the business chances to develop such systems. For

example, they supported to develop robot systems displayed at EXPO'05 at Nagoya Area, in which university researchers have had exposition of advanced robot systems. Such robot systems are very difficult to develop, because of the severe environment for display over 100 days. Figure 4 depicts a sample robot with reinforcement learning capabilities.

Fig. 4. Example of the Robot Project and Exhibition of Suwa Industrial Accumulation

2) Cooperate with Industrial and University People
Traditionally, the cooperation of industries and universities has been considered as the linear model, in which university researchers provides seeds of new technologies to industry people, who utilize the technologies into practice. The linear model means that technologies are moved into practice through basic research, applied research, prototype development, and markets. The model is traditional because of the continuous success of natural sciences such as physics. However, in these ICT era, the road from information, systems, and services to business is much more important. SIARC are seeking for such a non-linear model for new industries. They need the concepts of not only engineering disciplines but also business management, economics, and regional activities.

3) Implement New Visions
The visions of SIARC are shown as follows (see Figure 5):
- Market research on the tacit requirements in universities and research firms
  This includes coordination of experimental development, consultation of research and development, project and program management, and proposal on new businesses;
- Consultation of regional management

This includes survey studies of the Suwa industry region, political decision making, and development sightseeing for usual people to understand manufacturing industries

- International cooperation management

  They have enough abilities to support rapid manufacturing development and implementation from all over the world. If regional and/or Japanese market were too small, they are able to have various requirements worldwide.

- Web site for manufacturing development to directly bridge consumers and manufacturers.

  They are developing the Web site Mono-City or DAIKOC (Dynamic Advisor for Information and Knowledge Oriented Communities) to encourage the activities of the area [3].

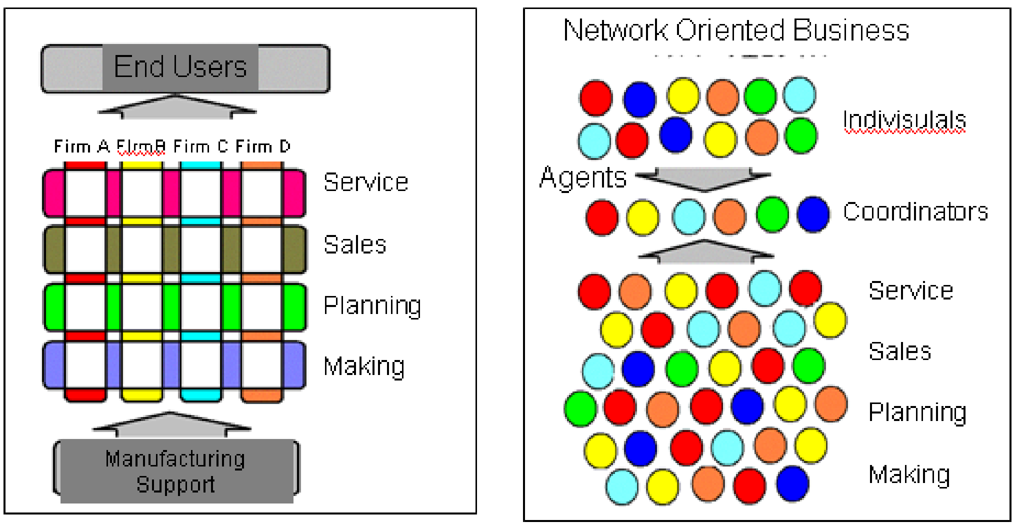


Fig. 5. Visions of New Manufacturing Industry Networks

References

[1] Tapscott, D., Silliams, A. D.: WIkinomics – How Mass Collaboration Changes Everything. Portfolio, 2006.

[2] Axelrod, R., Cohen, M. D.: Harnessing Complexity. Free Press, 1999.

[3] www.daikoc.net

3. High-Performance CFD-Based Global Optimization for High-Speed Multi-hull Ship Design

It is pointed out that the Human System Integration (HSI) should better be planned early in the design stage so that its impact on the total system effectiveness is greatest.

The Office of Naval Research with Dr. Pat Purtell as the ONR Program Officer, sponsored the subject project to develop `Simulation Based Design of Fast Multihull Ships` during 2005 to 2008. The participating organizations were; Univ. of Iowa (Prof. F. Stern), Osaka Prefectural University (OPU) (Prof. Y. Tahara), and Istituto Nazionale per Studi ed Esperienze di Architettura Navale
(Dr. E.F. Campana). The author participated, as a NICOP liaison at ONR Global, Tokyo.

Prof. Y. Tahara who contributed much in developing the general formulation high-performance CFD-based global optimization method assisted the author in summarizing the following research results.

In order to design a naval logistic ship, not only the ship's speed performance but also the ship`s motion characteristics have to be studied, so that the work efficiencies of military personnel onboard and flight deck operation should be taken into consideration.

In this sense this research is a fine successful example of the HIS initiative. The Genetic Algorithm (GA) was successfully applied to develop a large high-speed catamaran for logistic support under the collaborative research by the University of Iowa, Osaka Prefectural University and INSEAN, Italy under the sponsorship of ONR. This joint research has successfully demonstrated a method of ship design optimization to secure high operational capability, by introducing HSI concept in the early stage.

Ship Hull Design Optimization and Human System Integration

----An International Collaborative Project----

Summary

The object of the present research is to develop general formulation high-performance CFD-based global optimization method and overcome the limitations of optimal design tools based on local optimization methods via the development and application of global optimization algorithms. These include the categories: CAD-based hull form modification for high-speed ships, multi-objective genetic algorithm (MOGA) and scalable message passing interface (MPI), and CFD method which is capable for application to high-speed ships. The resulting optimization software will be applied to the solution for high-speed ship design problems and an experimental activity will be carried out to assess the success of the optimization process. This research project is based on close interactions with both IIHR (U. Iowa) (Professor F. Stern) and Instituto Nazionale per Studi ed Esperienze di Architettura Navale (INSEAN) (a coordinated NICOP proposal) (Dr. E.F. Campana).

The plans for Years 1 (Apr. 2005 - Mar. 2006), 2 (Apr. 2006 - Mar. 2007) and 3 (Apr. 2007 – Mar. 2008) are summarized as follows:

Year 1 - Analysis, selection, development, and implementation of the basic algorithms. Selection of initial ship problem. Paper publication.

Year 2 - Select and compare two best algorithms. Test on single-objective function ship problem. Verify by experiment. Paper publication. And,

Year 3 - Develop multi-objective function approach. Test on ship problem. Verify by experiment. Paper publication.

In the following, an overview is given of current progress in Year 3 (Aug.2007-Mar.2008).

- SBD WITH RANS ANALYSIS

Adopted optimizer module is based on Real-coded Multi-Objective Genetic Algorithm (RC-MOGA). A drawback of GA-based approach is larger computational load than gradient-based optimization algorithms. In the present study, the problem is overcome by introducing parallel computing technique, i.e., Message Passing Interface (MPI) protocol together with MPI group communication architecture. Fig.6 illustrates the present approach. It has been shown that optimization performance is dramatically enhanced. A CAD-based, geometry blending type approach is used to yield modified hull forms. CFD method is CFDSHIP-IOWA version 4, which is a general-purpose, multi- block, high performance parallel computing, unsteady RANS code developed for computational ship hydrodynamics.

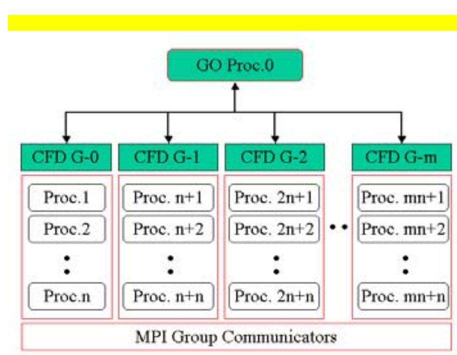
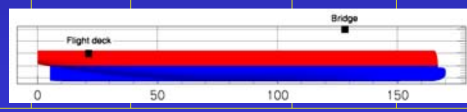


Fig. 6. High-performance parallel-computing architecture for multi-process CFD-based global optimization (GO) algorithm.

Test #ID	Geometry	Objective Function	Geometrical Constraints	Functional constraints
3	Catamaran	**Multi-Objective Problem** ***Minimize*:** $\begin{cases} F_1 = R_T(Fr) \\ F_2 = 0.5\dfrac{\ddot{z}_B}{0.2g} + 0.5\dfrac{\dot{z}_D}{1.0} \end{cases}$ For Fr=0.541 Where, B and D are bridge and flight deck for the ship free to sink and trim.	**As in problem #1**	**As shown below:** a. $\dfrac{R_T(0.460)}{R_T^{org}(0.460)} \le 1.0$ b. $\dfrac{R_T(0.622)}{R_T^{org}(0.622)} \le 1.0$ c. $\ddot{z}_B \le 0.2g$ d. $\dot{z}_D \le 1.0m/s$



Tab. 1 – Definition of optimization test case.

The above-described schemes compose a RANS-based optimization scheme to demonstrate HSSL-B optimization test case. In the present study, optimization test case No.16 in Tab.1 is performed, where that problem involves two objective functions, i.e., F_1 and F_2, corresponding to combined total resistance R_T for three speed and sea-keeping performance, respectively. That is, resistance and sea-keeping quality are simultaneously optimized. The optimization was performed at OPU by using recently upgraded PC Cluster environment with Intel Xeon-3070 2.66 GHz. The system parameters of RC-MOGA are as follows: crossover rate = 0.75, and population size = 12. The computation is continued up to 60 generations. Fig.7 shows distribution of solutions for optimization. It is seen that the Pareto optimal set was successfully detected, and designs on the set indicate significantly reduced both the objective functions. In order to evaluate trends in geometry and flow, ID-151 design was selected for model test, which is currently in progress. Fig. 8 and 9 show comparison of the geometry and flow between the original and optimal designs on the Pareto set.

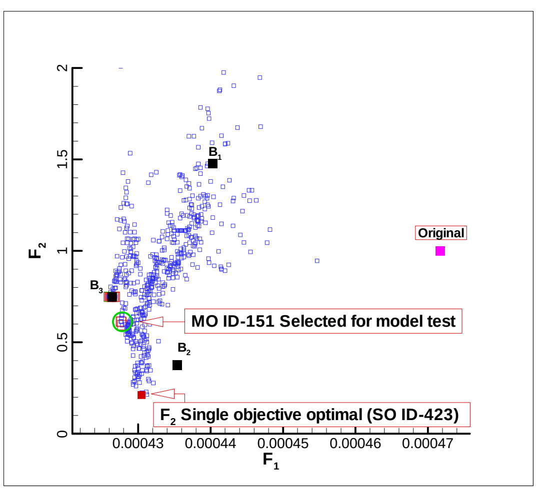


Fig. 7. Distribution of solutions from the present optimization.

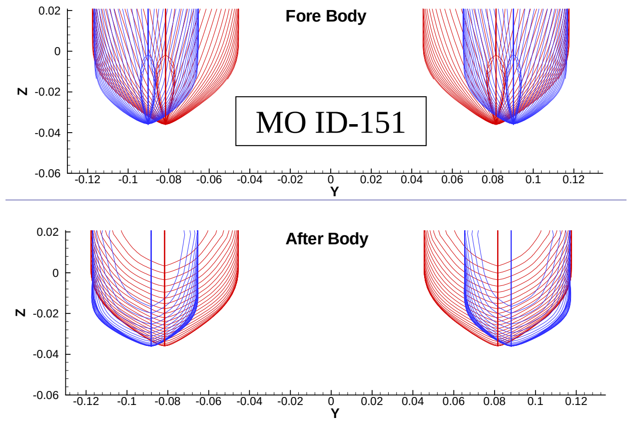


Fig. 8. Comparison of geometry.; red and blue lines are original and optimal hulls, respectively.

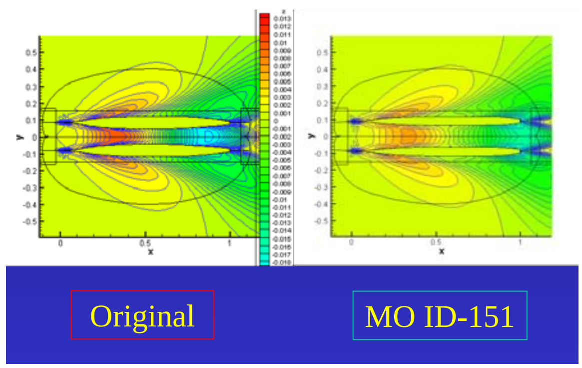


Fig. 9. Comparison of wave contours.

ADVANTAGE OF EVOLUTIONARY ALGORITHM

In the present study, adopted optimizer module is based on Real-coded Multi-Objective Genetic Algorithm (RC-MOGA). Fig.10 illustrates differences in strategy between Successive Quadratic Programming (SQP) and Genetic Algorithm (GA). Both approaches are representatives of gradient-based algorithm and probabilistic (or evolutionary) algorithm, and are widely used in engineering applications. SQP is able to efficiently search optimal if the initial point is correctly given. In contrast, GA is capable for global optimal search, and does not require evaluation of gradients. Another importance of GA is extendable feature for Pareto optimal finder in multi-objective optimization, and parallel computing. A drawback of GA-based approach is larger computational load than gradient-based optimization algorithms. In the present study, the problem is overcome by introducing parallel computing technique, i.e., Message Passing Interface (MPI) protocol together with MPI group communication architecture. Fig.10 illustrates the present approach.

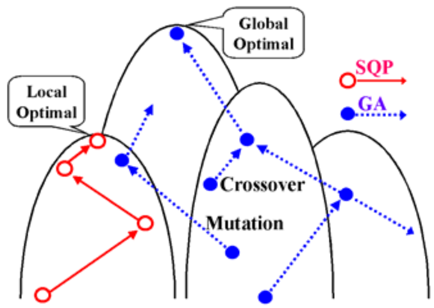


Fig. 10. Optimization by Genetic Algorithm.

Publications.

Y. Tahara, EF. Campana, D. Peri, A. Pinto, M. Kandasamy, F. Stern (2007) Global Optimization and Variable Fidelity Strategies in the Single and Multiobjective Optimal Design of Fast Multihull Ships. 9th International Conference on Numerical Ship Hydrodynamics, August 5-8, Ann Arbor, Michigan, USA.
EF.Campana, D.Peri, Y.Tahara, F.Stern, (2006) Shape Optimization in Ship Hydrodynamics Using Computational Fluid Dynamics. J. Computer Methods in Applied Mechanics and Engineering 196: 634–651

Y.Tahara, S.Tohyama, T.Katsui, (2006) CFD-Based Multi-Objective Optimization Method for Ship Design. International J. Numerical Methods in Fluids 52:449-527

E.F. Campana, D. Peri, Y. Tahara, M. Kandasamy, F. Stern, C. Cary, R. Hoffman, J. Gorski, C. Kennell (2006) Simulation-Based Design of Fast Multihull Ships. Twenty-Sixth Symposium on Naval Hydrodynamics, September 17-22, 2006, Rome, Italy

4. Decision Making Training through Gaming Simulation and Agent-Based Modeling

Gaming Simulation is an effective method to virtually experience and learn business schemes in the real world. It is recognized and used in a wide range of educational institutions[1]. Case Method of the Harvard Business School is also an effective educational method and is widely adopted in various fields in the name of Case Study [2]. Gaming Simulation and Case Study are the mutually independent methodologies and have evolved separately making the most of their advantages. There have been few studies that attempt to integrate these methodologies.

Furthermore, so far, it has been considered very difficult even for experienced experts to develop a suitable simulator. To overcome the difficulties, the introduction of multiple software agents is critical. Human-agent participation into a gaming simulator has the following roles: (i) to substitute human players by software agents, (ii) to understand the decision making procedure by implementing agent functionality, (iii) to speed up the game development by tuning the game parameters, (iv) to control the game balances by agent participation during the game executions, and (v) to explore desirable business processes by machine learning agents.

Based on the background, we have been intensively studying the integration of these two methodologies through the following processes [4]:

1) Model the business actions of corporate managers in the areas of *decision-making* and *operations* separately in order to create a gaming scenario, which is applicable to various cases,
2) Develop a versatile business simulator based on the model of *decision-making* area using BMDL/BMDS (Business Model Description Language/Business Model Development System) [3] business game developing toolkit, and
3) Implement a case on the simulator into an actual business game. As a concrete example, we develop a business game based on the scenario of the *operation* area of "Asahi Super Dry" case.

The basic architecture of BMDS/BMDS is summarized as follows: A model developer describe his or her business model in BMDL. A business simulator written in BMDL is first translated into corresponding CGI scripts and Java programs by BMDL translator. We are able to add software agent players to BMDS. The programs are then run on a server computer with a web browser and the model variable data in the form of spreadsheets. Finally, players execute the simulation through browsers on the web environment. BMDS manages the input information availability, simulation calculations, simulation rounds, views of public, team, and analysis data. Game players can input and modify the input variables based on public and team-specific information and their decisions.

The architecture of Business Model Description Language, Agent Rules, and Business Model Development System and sample learning sessions are shown in Figure 11.

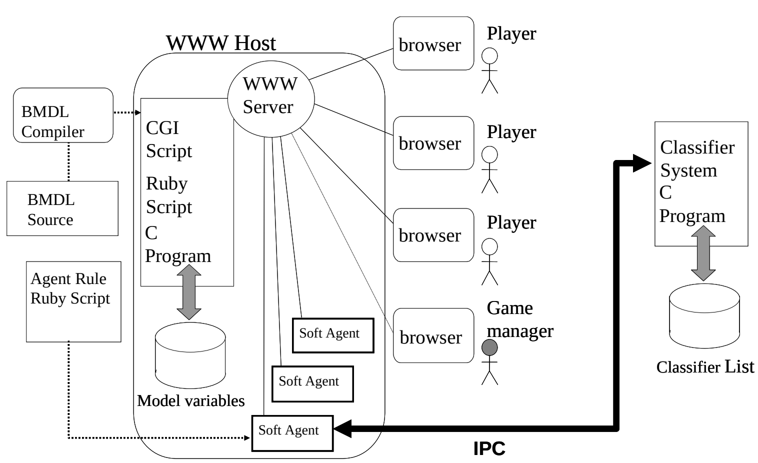


Fig. 11. System architecture of the business simulator and collaborative learning sessions.

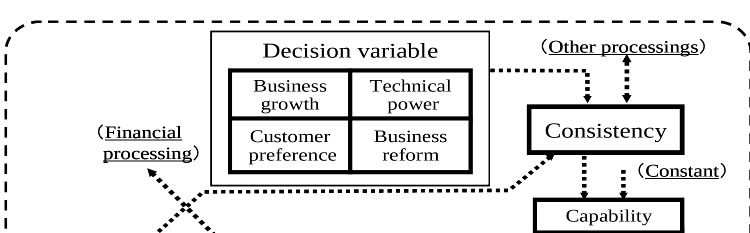


Fig. 12. Framework of decision-making processes of corporate management.

Plural players including both human and software agents participate in a generated game in a step by step round mode. A game manager controls the game play at every round, that is, the manager lets the players make their decisions. After confirming the inputs of all human players, the game manager executes the function of software agents, and then proceed the round. Such roles of the game manager are quite common in gaming simulation literatures.

.

Using BMDL/BMDS, we have developed a general framework of decision-making processes of corporate management shown in Figure 12. The framework has been used to implement a business game on the business operations of Asahi Breweries, one of the major breweries in Japan, in the period between 1982 and 1989, which is shown in Figure 13. In this period, Asahi made a great stride with the drastic corporate revolution and the smash hit of *Super Dry*. The important operational actions in this period were the revolutions of backbone, marketing, and Research & Development (R&D) operations.

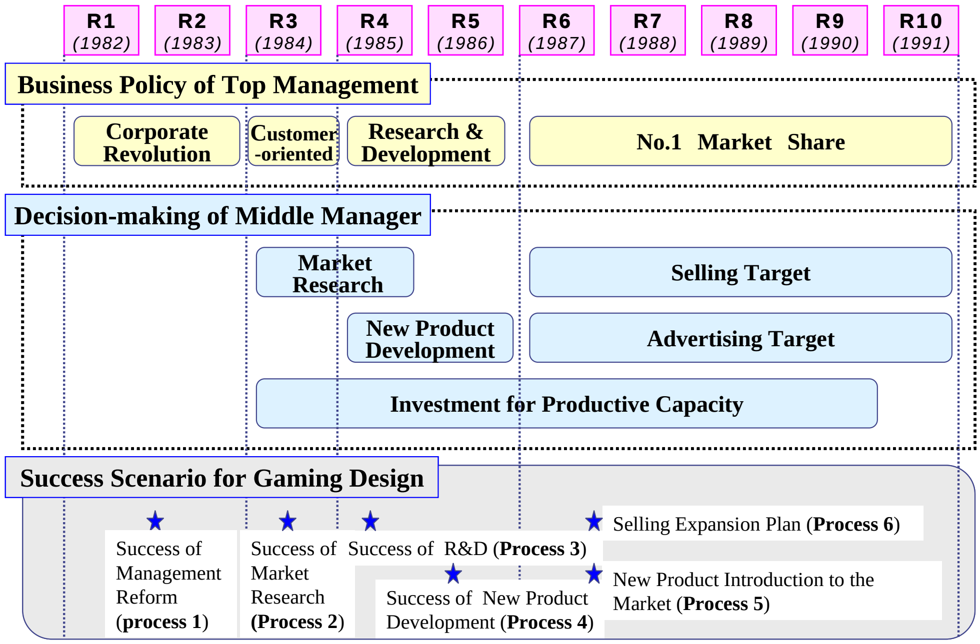


Fig. 13. Decision process and history of asahi brewery case.

From Intensive experiments, we have concluded that the proposed methodology with gaming simulation, mixture of human- and software agent-players, and business cases is very powerful and effective to train decision makers in the business management domains.

References

[1] Shirai, H., Tanabe, M., Kuno, Y., Suzuki, H., Terano, T., Tsuda, K.: Game development toolkit for business people in Japan. Simulation/Gaming, Vol.34, No.3 (2003) 437–446.

[2] Barnes, L.B., et al.: Teaching and the case method: Text, cases, and readings, 3rd ed. Boston, MA: Harvard Business School Press. (1994).

[3]. Terano, T., et al.: Understanding your business through Home-Made simulator development. Developments in Business Simulation and Experiential Learning, Vol. 26, (1999) 65-71.

[4] Kenji Nakano, Shinako Matsuyama, Takao Terano: Research on a Learning System toward Integration of Case Method and Business Gaming. Proc. AESCS 2005 (4th International Workshop on Agent-based Approaches in Economic and Social Complex Systems), pp. 25-34, 2005.

5. Application of Genetic Algorithm to Plant Design Problems

To solve the design problems for engineering plants, so far, they start the actual tasks after detailed requirement specifications have been completed. They usually use Monte Carlo simulations with numerical differential equation solvers in order to determine various system parameter settings. They must also validate the robustness of the parameter sensitivities. It takes 10-30 seconds cpu times on a standard workstation to run the numerical solver. This means that the Monte Carlo simulation is very time consuming task and if the specification would change, they must restart the calculation from the very first stage.

We are required to start the new plant system design before the detailed specifications are given. When the first design plan is given, we must start the design process, although it is incomplete. Thus, we will utilize rough information, which is obtained from the past design experience of similar plants. Our approach is to generate multiple design plans within the first requirement specifications, then to estimate the range of the feasible region among the plans.

A genetic algorithm (GA) based method is summarized as follows:

1) To apply conventional GAs, we digitize the target plant parameters;
2) We simplify the numerical solver to shorten the CPU time to get the numerical solutions;
3) We apply the hybrid technique with GA and Tabu-search. Tabu-search is a conventional heuristic technique in Operational Research Literature. The technique is used in GA in order to avoid to reach local optima in the optimization process.
4) We execute local search procedures among the solutions through the hybrid algorithm in order to validate the robustness of the feasible regions;
5) We determine the detailed parameter values using the full-spec numerical solver, after the requirement specifications are determined.

References

[1] Setsuya Kurahashi, Takao Terano: A Genetic Algorithm with Tabu Search for Multimodal and Multiobjective Function Optimization. Proc. the Genetic and Evolutionary Computation Conference (GECCO-2000), pp. 291-298, 2000.

[2] Y. Katsumata, S. Kurahashi, and T. Terano, “We Need Multiple Solutions for Electric Equipments Configuration in a Power Plant - Applying Bayesian Optimization Algorithm with Tabu Search,” *WCCI 2002 (2002 IEEE World Congress on Computational Intelligence)*, pp.1402-1407, May 2002.

[3] Takao Terano, Masakazu Takahashi, Kazutoshi Hanzawa: Multiple Solutions for Plant Design Analyses through a Genetic Algorithm with Tabu Lists. Proc. IEEE SMC 2006, pp. 3126-3131, Oct., 2006.

6. Extracting Tacit Knowledge of Plant Operations through Machine Learning and Data Mining Technologies

Continuation processes in chemical and/or biotechnical plants always generate a large amount of time series data. However, since conventional process models are described as a set of control models, it is difficult to explain dynamic and complicated plant behaviors. As human operators are unconscious of their tacit knowledge to control the plants, it is effective to extract such knowledge from plant operation data.

We have developed a novel method for the purpose [2]. The method consists of the following phases: (1) Reciprocal correlation analysis, (2) Implementation of a process response model, (3) Extraction of control rules, (4) Extraction of a workflow, and (5) Detection of outliers. To develop the model, we have utilized a novel techniques of Learning Classifier System [1], which is one of genetics-based machine learning and data mining methods. The continuous effort (KAIZEN) to improve the analysis phases are illustrated in Figure 14.

Although there are so many theoretical researches on Learning Classifier Systems (LCSs), however, very few applications have been reported in the literature. The proposed method is concerned with a practical application of LCSs in order to extract of plant operation knowledge from actual operation data of a biochemical plant. So far, many kinds of automatic control systems have been established in such plants as biochemical plants. Operator confirmation and manual procedures are essential for a wide variety of products used in small quantities requiring stringent quality control, such as advanced materials. Transfer functions like the delay time function have built up a process model by describing an individual response process. However, process circumstances might change significantly, according to variations of infused material stuff or operating conditions. Thus, automated acquisition or data mining of processes from actual daily data is desirable to manage these changes. We have developed a heuristic search method for plant operation rules, which could provide guidance on human operators, building up a process response model from a large amount of time series data. The basic principles of the model are 1) to maximize the correlation coefficient among time series data, and 2) to apply LCSs with Minimum Description Length (MDL) criteria.

We are concerning a biotechnical plant with a distillation tower as in Figure 16. In the distillation tower, low-pressure treatment performs constituent separation after the basic ingredient is infused into the tower. From complex plant data in Figure 15, we can obtain the following simple rules:

If 25% < F3 <= 50%, and
    75% < F4, and
    F3 is down,
        then 75% < T2

If F3 flow is from 25% to 50%, and
    F4 flow is 75% or more, and
    F3 flow is down, then
    T2 temperature becomes 75% or more

Using the proposed method, we also generate workflow processes for operations. First, we collect event data such as switching and value setting operations with time stamps. Then, using the proposed methods, we search for rules during given time intervals. Finally, we sort the acquired rules with the time key, then we get the corresponding workflows. For example, such a rule is obtained, which states: If switch 1(blower) is turned on, the state on surface of the product will confirm ”sticky” in 15 minutes, and switch 2(chiller) is turned on, dry temperature T2 will become 25% or less in 20 minutes. The rule is easily converted to the workflow shown in Figure 14.

Although the rule seems very small, however, process in the workflow occurs certainly on the condition. The method enables even human expert operators to support to discover implicit plant operation knowledge from both operation manuals data and process data. Such knowledge is useful to transfer experts’ special skills to naive operators.

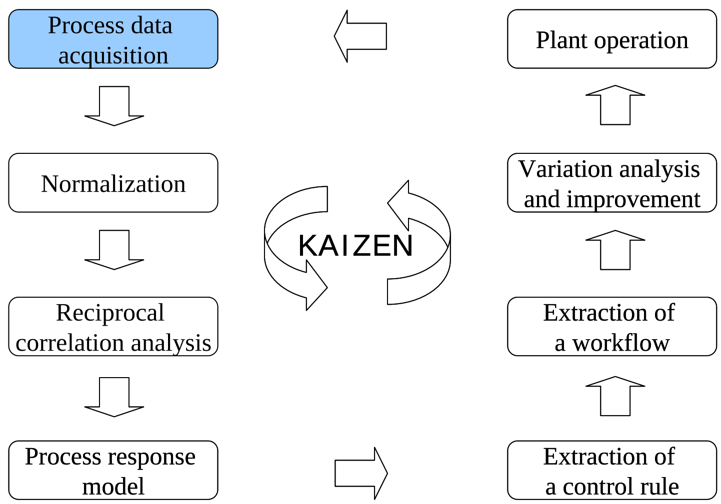


Fig. 14. Improvement of the analyzing process

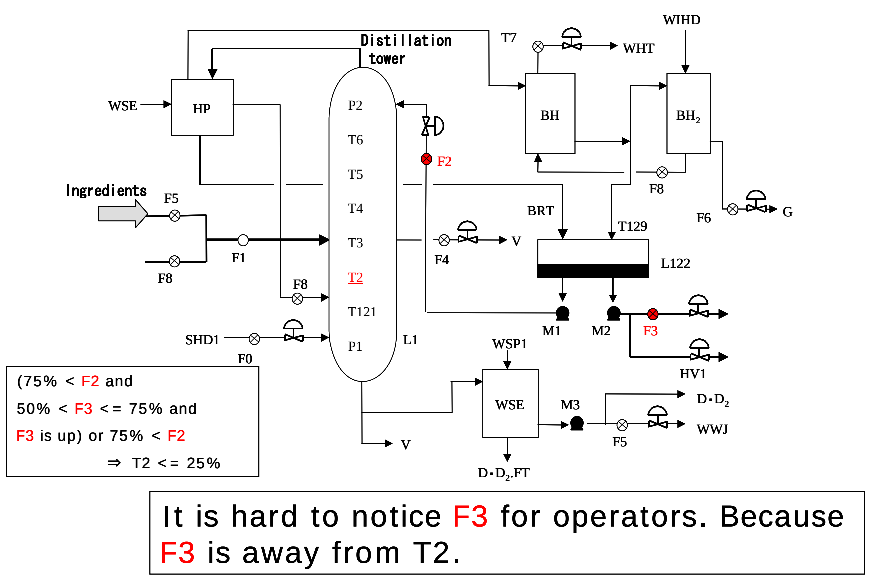


Fig. 15. Outline of the targeted biochemical plant and operation rules.

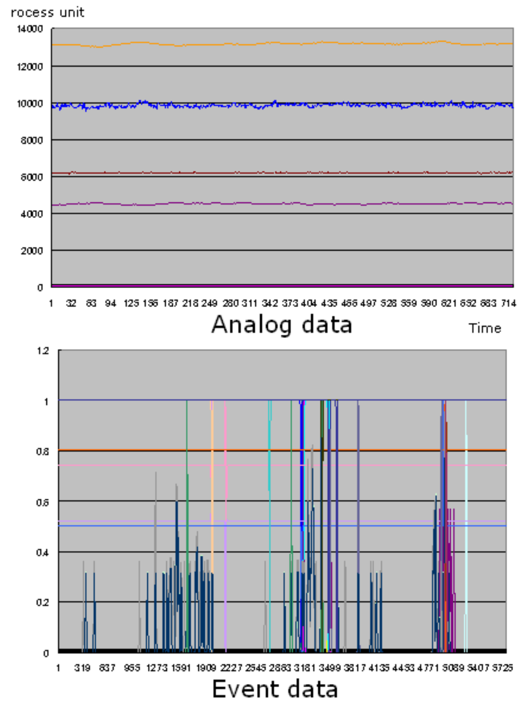


Fig. 16. Example of plant time series data.

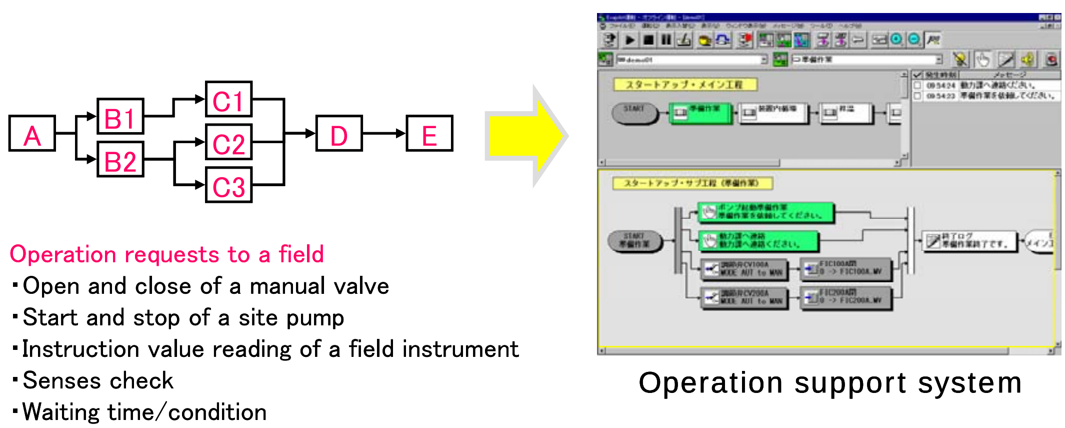


Fig. 17. Extracted workflow and support system.

References

[1] M. V. Butz, M. Pelican, X. Llora, and D. E. Goldberg. Extracted global structure makes local building block processing effective in XCS. IlliGAL Report, 2005011, February 2005.

[2] Setsuya Kurahashi, Takao Terano: Technology Extraction for Future Generations from Process Time Series Data Reflecting Expert Operator Skills", International Workshop on Learning Classifier Systems (IWLCS 2006/GECCO 2006), Workshop 142, 2006.